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The Cygnus X region XXIII. Is 18P87 galactic or extragalactic?

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The radio source 18P87, previously thought to be a point source, has been serendipitously found to be resolved into a core-jet geometry in VLA maps. H I absorption of continuum emission (in data from the Canadian Galactic Plane Survey) appears in gas with radial velocities $> +2$ km/s but not in brightly emitting gas at lower radial velocity. Examination of further archival observations at radio, infrared and optical wavelengths suggests that the "obvious" interpretation as a radio galaxy requires a rather unusual object of this kind and a highly unusual local line of sight. We argue that 18P87 may be a Galactic object, a local astrophysical jet. If this is correct it could have arisen from outbursts of a microquasar.

1   Introduction

Our surveys of the Cygnus X region (Wendker, Higgs, & Landecker 1991, Paper XVIII) generated several follow-up observations at higher resolution with the VLA. In one of these we serendipitously found that the source 18P87 was resolved into a structure that at first glance resembles a faint radio galaxy and we did not investigate it more thoroughly. However, while perusing continuum absorption by H I in data from the Canadian Galactic Plane Survey (CGPS - Taylor et al. 2003) we found that 18P87 shows H I absorption for only a small part of the local gas, which is quite unexpected for an extragalactic source. In this paper we present the available observations and examine the possibility that the source is Galactic.

2   Observations

2.1   18P87 in CGPS and other survey data

The large-scale brightness distribution around 18P87 can be seen in a 21-cm continuum map (Fig. 1) taken from the CGPS (for which observation and imaging techniques are described in detail in Taylor et al. 2003). Observational details relevant to Fig. 1 are given in Table 1. 18P87, first catalogued at 408 MHz in Paper XVIII, is the double source near the centre of the image; it is clearly resolved in Fig. 1 at a resolution of $\sim 1'$ into north-west and south-east components (18P87NW and 18P87SE). The remaining resolved structure in this image is faint H II.

The general area, in the south-east of the Cyg-X region, is less crowded with bright H II regions than other parts of

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Table 1   Parameters of the DRAO CGPS data.

CGPS mosaic MN1	(release April 2002)
Centre frequency	1.420 GHz
Data product	Stokes I
Synthesized beam	$71.5'' \times 49.1''$, PA $-36.2°$
rms noise	40 mK
Line synthesized beam	$85.4'' \times 58.6''$, PA $-36.0°$
rms noise	2.5 K
Radial velocity coverage	-164 to $+58$ km/s
Channel spacing	0.82446 km/s
Velocity resolution	1.32 km/s

Data available from www1.cadc.hia.nrc.gc.ca/cgps

the complex. This eases the derivation of point-source parameters, but the error budget is still dominated by interpolation of the local background. As the resolution of these surveys (and other archival data that we have used) is around $1'$ and both components of the double source appear to be unresolved, we have fitted Gaussians to the data using the DRAO software routine FLUXFIT. Equatorial and Galactic co-ordinates are listed in Table 2. In Table 3 we summarize the flux densities of both components, either taken from Gaussian fits to the quoted survey data or directly from the references. The VLA flux densities are integrated values; see Sect. 2.3.

The sources are definitely nonthermal. Least squares fitted spectral indices ($S_\nu \propto \nu^\alpha$) to all data are -1.1 and -0.7 for 18P87NW and 18P87SE respectively with errors around ± 0.3 dominated by the scatter of the low-frequency values.

2.2   H I continuum absorption

Even quite weak continuum sources show absorption by H I in the CGPS 21-cm line data. Strasser & Taylor (2004)
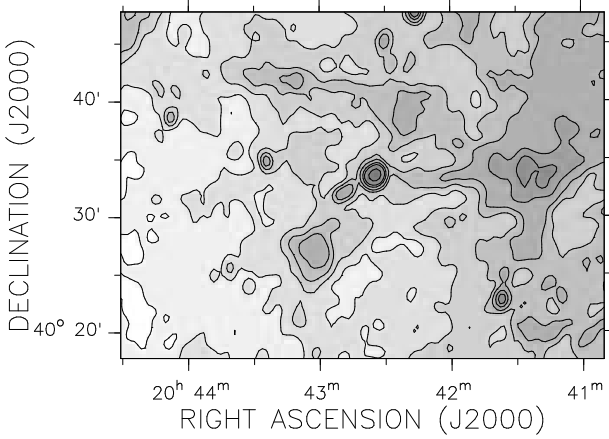
Fig. 1 Continuum map of the CGPS area of 18P87 at 21 cm. 18P87 is the double source aligned NW-SE at map centre.

Table 2 Equatorial and Galactic positions of 18P87.

Component	Position
18P87NW	$20^{\rm h}\,42^{\rm m}\,34.8^{\rm s}$ /$+40°\,33'\,43''$ (J2000)
	$80.6928°/-1.0699°$ (l,b)
18P87SE	$20^{\rm h}\,42^{\rm m}\,49.4^{\rm s}$ /$+40°\,32'\,18''$ (J2000)
	$80.7026°/-1.1207°$ (l,b)

Table 3 Summary of flux densities of 18P87.

Frequency [MHz]	18P87NW [mJy]	18P87SE [mJy]	Obs. Date	Ref.
327	234±10	40±8	1991	1
365	< 400		1974-1983	2
408	500±70		7-8/1985	3
408	423±36		12/95-01/96	4
1400	76±3	11±2	28/04/1995	5
1420	94±3	17±3	12/95-01/96	4
1465	62±3	16±2	17/05/1988	4
4800	< 20	< 20	05/74	6
4850	< 18	< 18	11/86-10/87	7
4885	33±2	6±1	22/08/1988	4

1 WENSS, Rengelink et al. (1997); 2 Douglas et al. (1996);
3 Paper XVIII, Wendker et al. (1991); 4 CGPS, this paper;
5 NVSS, Condon et al. (1998); 6 Paper XV, Wendker (1984);
7 Gregory et al. (1996)

Fig. 2 The H I continuum absorption by local gas is shown for 18P87NW. The top solid line is the off-spectrum, the dashed line the on-spectrum, and the bottom solid line the difference, on − off.

discuss this for a large sample of *bona fide* extragalactic sources. Following the method outlined in Behre et al. (2004, Paper XXII) we derived the absorption spectrum of 18P87 and several other (extragalactic) point sources in the neighbourhood. 18P87SE is too weak to produce a believable optical depth signal, but 18P87NW is strongly absorbed in the local gas. In Fig. 2 we show on-source and off-source spectra for 18P87 together with the difference spectrum, on minus off. Significant absorption is evident at velocities +2 to +18 km/s. In Fig. 3 we examine the data as an optical depth spectrum, together with similar spectra for the nearby comparison sources 18P79 and 18P91, both about half a degree
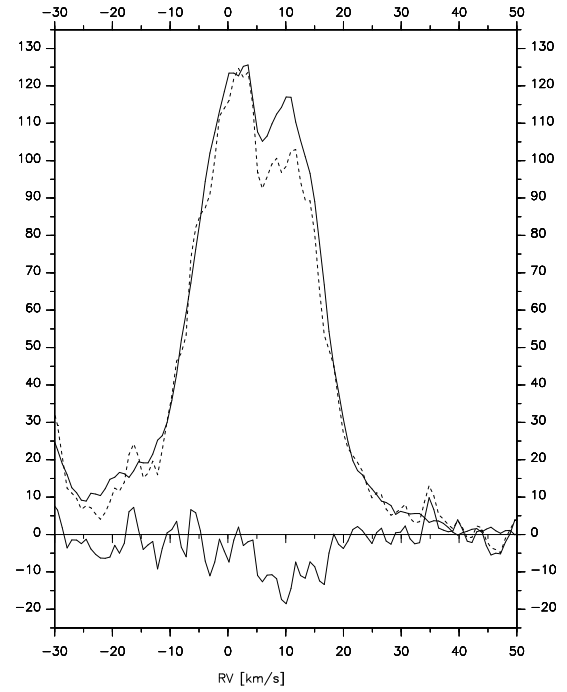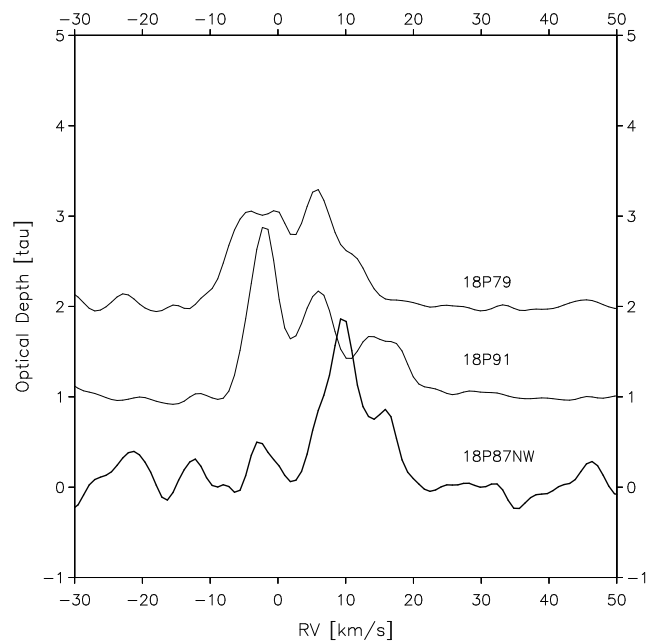

Fig. 3 Optical depth spectra for 18P87NW, 18P91 (offset by $\tau = 1$), and 18P79 (offset by $\tau = 2$). These spectra have been smoothed by fitting spline functions (see text).

distant. These spectra have been smoothed by fitting a cubic spline function to each. The rms noise, σ, in each unsmoothed spectrum was estimated from channel-to-channel variations, and a spline function was fitted such that the rms deviation between smoothed and unsmoothed data was less than σ. Values of σ are 0.15, 0.059, and 0.19 for 18P87NW, 18P79 and 18P91 respectively.

18P79 and 18P91 show significant optical depths, τ, typically 1 to 2, in all local H I (velocities +25 to −15 km/s) and indications of absorption in the Perseus and outer spiral arms (at velocities more negative than those shown in Figs. 2 and 3). 18P87NW shows significant optical depth (up to $\tau = 1.8$) but there is an important difference between 18P87NW and the other (extragalactic) sources. For the latter H I absorption is seen at *all* local velocities, while 18P87NW shows absorption only down to a radial velocity of about +2 km/s, just including the self-absorption feature which produces the apparent split of the emission peak into two maxima (Fig. 2). There is a remarkable absence of absorption corresponding to the very strong peak at ∼0 km/s in the emission spectrum (see Fig. 2), and this suggests very strongly that 18P87 lies *within* the local gas.

2.3 High-resolution VLA observations

In VLA[1] observations taken for another purpose we discovered that 18P87 is resolved into a two-lobed structure. Telescope parameters for 1465 and 4885 MHz are summarized in Table 4. At 4885 MHz low- and high-resolution images were made. As 18P87 is situated off-centre in both observations, the maps were corrected for primary-beam attenuation using the standard VLA prescriptions. In an image made simultaneously at 8415 MHz the source is too far down the primary beam to allow derivation of useful data.

VLA maps of 18P87 are shown in Figs. 4 and 5. At typical resolutions of several arcseconds 18P87 is resolved into a two-lobed structure about ∼5′ in overall length and ∼0.5′ in width. At both 1465 and 4885 MHz data from C and D configurations of the VLA were combined, and *u-v* coverage allowed complete imaging of objects of this size without any loss of broad structure. At first glance the structure is typical of a radio galaxy with two jets. The images can be approximated by a series of aligned knots with typical extent ∼10″ immersed in a faint elliptical envelope around each lobe. The NW lobe contains three such knots and the (longer) SE lobe four. We will show that the fifth knot in the SE lobe, not aligned with the dominant source structure, is an unrelated foreground object. The 1465 and 4885 MHz flux densities listed in Table 3 are integrated values from Gaussian fits. Flux densities derived from the low- and high-resolution maps at 4885 MHz agree closely, and the difference in appearance arises only from resolution effects. At 4885 MHz a faint knot is situated more or less centrally

Table 4 Parameters of VLA observations.

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Field centre 1465 MHz:	
α(B1950)	$20^{\mathrm{h}}\,41^{\mathrm{m}}\,01.0^{\mathrm{s}}$
δ(B1950)	$40°\,19'\,00''$
On-source time C+D	37 min
Synthesized map size	$42.58' \times 42.58'$
Synthesized beam	$20.9'' \times 19.0''$, PA 61°
Surface brightness conversion	1 Jy/beam ↔ 1434 K
Field centre 4885 MHz:	
α(B1950)	$20^{\mathrm{h}}\,41^{\mathrm{m}}\,01.0^{\mathrm{s}}$
δ(B1950)	$40°\,19'\,00''$
On-source time C+D	37.4 min
Synthesized map size	$12.77' \times 12.77'$
Synthesized beam 1	$13.2'' \times 10.8''$, PA 64°
Surface brightness conversion	1 Jy/beam ↔ 359.3 K
Synthesized beam 2	$5.5'' \times 4.4''$, PA 175°
Surface brightness conversion	1 Jy/beam ↔ 2117 K
C configuration; 20 and 6 cm	1988 May 17
D configuration; 20, 6, 4 cm	1988 August 22
Calibrators:	
flux density	3C 286
phase	2050+364
polarization	3C 138
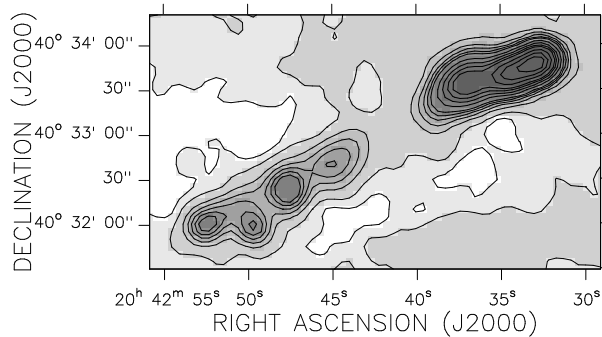
Fig. 4 1465 MHz VLA map of 18P87, resolution ∼20″. The contours are manually selected to show the salient features. The contours and the colour transitions correspond to -0.5, 0, 1, 2, 3, 4, 5, 7.5, 10, 12.5, 15, 20, 25, and 30 K.

between the two lobes; we will refer to it as the central knot. Its deconvolved size is 2 to 3″ at 4885 MHz. At 1465 MHz it is not detected, probably because its spectral index is flatter relative to the lobes, but also because of the slightly poorer angular resolution.

Spectral indices derived from the integrated flux densities of the lobes between 1465 and 4885 MHz are quite similar, −0.52 and −0.81 for the NW and SE lobes respectively, but these values may be affected by variability (see below). We produced a pixel-by-pixel spectral index map at the resolution of the 1465 MHz map; while the errors are large the mean values are consistent with the above estimates. However, there is a strong and consistent trend of rising spectral index from the central knot ($\alpha \sim -1.5$) to
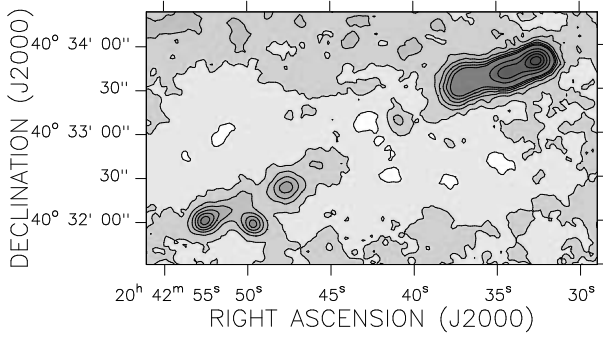
Fig. 5 4885 MHz VLA map of 18P87, resolution ~13″. The contours are manually selected to show the salient features. A central source can be seen. The contours and the colour transitions correspond to -0.10, 0.0, 0.1, 0.2, 0.3, 0.4, 0.5, 1.0, 1.5, 2.0, and 2.5 K (colour in online edition).

the edge ($\alpha \sim -0.5$). A similarly definite trend appears in spectral indices derived from fitted Gaussian components; individual values are noisy but the trend is there.

2.4 Other observations

Central sources of jets are often variable, and we have searched the available data (presented in Table 3) for signs of such activity. We consider the 6-cm data first. The errors quoted on the new measurements are from the fitting procedure alone. The older data do not contribute much, as they were obtained with lower resolution than our VLA maps. For the bright component (18P87NW) variations at the 5 to 6σ level could have escaped detection. At this wavelength we can say only that the source could have brightened slightly over the time span (1974 to 1988) of the available data.

Examining the 21-cm data, we find that the values for 18P87SE are compatible with no variability, although there is a small probability that the measured values could have been influenced by activity of the foreground star (see Sect. 2.5). On the other hand, 18P87NW appears to have brightened in the course of 8 years. We are comparing observations VLA data from 1988 with data from the DRAO Synthesis Telescope obtained in 1996 (see Table 3). The two datasets are aperture-synthesis observations of an extended source made with slightly different u-v plane coverages, but these differences are of no practical consequence for observations of 18P87NW whose extent is ~2′, and we consider the evidence for variability at 21 cm is strong. Light time arguments immediately imply that the brightening cannot have affected the whole extended source but must have arisen from a small component, either from one of the knots visible in the VLA maps or from an outburst in the central source.

Synchrotron radiation is intrinsincally highly polarized. Examination of the CGPS polarization data at 1.4 GHz (Landecker et al. in prep.) shows features of extent a few arcminutes in the surroundings of 18P87 whose polarized intensity

is ~1.3 mJy/beam, but no polarized feature can be unambiguously associated with 18P87. This translates to an upper limit of 1.4% for 18P87.

Examination of the POSS and 2MASS surveys reveals no optical or infrared structures or point sources which could be identified with the lobes or their substructures; for the one exception see Section 2.5. The same is true for the near and far infrared bands of the IRAS and MSX maps. The central knot has no apparent optical or near-infrared counterpart.

2.5 A stellar foreground source

The VLA maps at 1465 and 4885 MHz (Figs. 4 and 5) show one knot which is conspicuously not aligned with the main axis of the radio lobes. Its peak position agrees quite well with the position of a star on the Palomar Observatory Sky Survey as well as in the 2MASS catalogue (J2000 position in the USNO B1.0 (Monet et al. 2003): $20^h 42^m 49.86^s$ $+40° 31′ 57.9″$). The colours deduced from these catalogues are compatible with an unreddened late-type foreground star of type around M0V with a wide range from early K to late M possible (Cox 2000). Its distance would be several tens of pc but definitely below 100 pc. Its detection at radio wavelengths suggests the star underwent a radio flare at the time of the VLA observations.

3 Galactic or extragalactic?

18P87 definitely is an astrophysical jet, but whether it is Galactic or extragalactic is not obvious. We compare the two possibilities based on the review of microquasars by Mirabel & Rodriguez (1999) and on the description of the prototypical radio galaxy Cyg A by Carilli & Barthel (1996). We also draw on the work of Fernini (2007) and O'Dea et al. (2009), who have examined the properties of Fanaroff-Riley Class II objects (Fanaroff & Riley, 1974). Radio galaxies are sufficiently abundant that finding one close to the Galactic plane (latitude about $-1°$) is quite plausible. On the other hand, Galactic jets are preferentially situated close to the Galactic plane. Both possibilities remain open.

The most important argument favouring a Galactic object is provided by the H I absorption (Sect. 2.2 and Figs. 2 and 3). H I continuum absorption of 18P87 is seen only for radial velocities larger than +2 km/s although both the on and off signals from local gas at more negative velocities are stronger. At +2km/s the optical-depth spectrum of 18P87NW (Fig. 3) shows a value of $\tau \approx 0.3$, no more than 2σ, while local gas at +10 km/s is producing a 10σ absorption. For the comparison sources 18P79 and 18P91 virtually the same local gas is producing absorption at the level of 7 to 30σ. If the same gas was in the line of sight to 18P87 there is no doubt that the observations would have had the sensitivity to detect absorption in it.

The usual interpretation of such behaviour is that the continuum source must be in front of all gas with a smaller

radial velocity. Hence the source must be Galactic. In view of the weight of this argument we tested whether the assumption inherent in deriving the absorption profile, that the scale of the H I gas is substantially larger than the extent of the source, is justified. We split the circumference of the ring defining the off profile into four quadrants. The qualitative appearance of the on − off profile in Fig. 2 was unchanged. Furthermore, along lines of sight to 18P79 and 18P91 (about 20 and 13 pc away at 2 kpc, respectively) we see strongly absorbing gas in the whole local interstellar medium. If this missing continuum absorption is a property of the H I gas this would be a very strange line of sight although numbers could be forced to produce the profiles. One would have to adjust the spin temperature above 600 K in a tunnel along the line of sight to 18P87 for radial velocities below +2 km/s, while all other indications point to 200 K or less. In view of the abundance of cool H I in this area of Cyg X we regard this as highly unlikely and conclude that the probability that 18P87 is Galactic is high.

In discussing a possible extragalactic origin, we compare 18P87 with FRII radio galaxies, those with prominent jet-powered lobes. Fernini (2007) and O'Dea et al. (2009) have examined a total sample of some 40 objects whose linear extent ranges from ∼60 to ∼600 kpc. If 18P87 fitted into this group of radio galaxies its distance could lie anywhere from 40 to 400 Mpc. The width of the jet of $10''$ (see Sect. 2.3) would correspond to a physical width of 2 to 20 kpc, credible values.

However, considering the morphological evidence, we see that the detailed geometry of 18P87 is not that of a typical radio galaxy. Although at first glance it seems to be an edge-brightened FRII object, it lacks the typical small-scale 'hot spots' in the lobes. In fact there are no extended lobes and if it is a radio galaxy it has only jets, with knots of emission lying in the jets (see the morphology of Cyg A in Carilli & Barthel 1996). Such a configuration is not observed in extended radio galaxies to our knowledge, but only on small (pc) scales in active galactic nuclei. The three pairs of knots in 18P87 are each aligned across the central source and the position angle shifts by about $5°$ going from the inner to the outer pair. This could easily be three hot spots belonging to a jet of a Galactic object, marking three consecutive working surfaces in a dense surrounding interstellar medium with typical sizes of 1.5 pc in length and about 0.15 pc in intrinsic width. In the extragalactic interpretation this behaviour is more difficult to accommodate.

Next we consider evidence from the radio spectrum. Radio galaxies tend to show a flattening of the spectrum from the central source to the outside. This is the case with 18P87. In radio galaxies the flattening is caused by old electrons which diffuse backwards from the working surfaces to the centre and which dominate the diffuse component in flux. In the case of 18P87 the spectral indices are dominated by the knots and not by a diffuse component. This is no problem for a Galactic jet as a slight precession in the jet could easily make the outer knots the youngest. The existence of a central source is compatible with both interpretations. That the central source has no optical or near-infrared counterpart is also plausible. Consider first the interpretation as a radio galaxy. The central core would be surrounded by an accretion disk and a torus, with two jets. The jets appear to lie close to the plane of the sky and the torus, orthogonal to the jet axis, could be in our line of sight to the core. Its dust and molecular gas would then absorb any optical or near infrared emission from the core. If 18P87 is a microquasar we do not expect a strong optical or infrared source at its centre. The temperatures of the accretion disks of microquasars with black holes of mass 1 to 10 M$_\odot$ at their cores are much higher than those of AGN. Rees (1984) shows that the disk temperature is $T \approx 2 \times 10^7 \, (M/M_\odot)^{-2.5}$, where M is the black hole mass. Mirabel & Rodriguez (1999) consider this the reason why they could find no optical or infrared counterpart of the central source of the first microquasar, 1E1740.7−2942 (Mirabel et al. 1992; Marti et al. 2000). We note that 18P87 and 1E1740.7−2942 are morphologically similar.

Variability is another consideration. In radio galaxies variability is usually confined to the central source. At 21 cm this could possibly be hidden by resolution effects (although a slight shift in the position of the NW maximum should have occurred). At 6 cm a total increase in the flux density of at least 10 mJy occurred between 1987 and 1988. As the flux density of the resolved central source is only ∼1 mJy this increase cannot have occurred there. The discrepancy can be resolved if the variability lies in one of the (northwestern) knots; such behaviour would be very unusual for a radio galaxy.

Finally, we consider the observed size of the source. As a Galactic source at a distance of 1 kpc, its physical size must be at least ∼1.5 pc (it may be larger, depending on the orientation of the jets to the line of sight). This is quite compatible with the size range of known microquasars: 1E1740.7−2942 has a jet ∼5 pc in length, GRS 1758−258 has an extent of 6.7 pc, while SS433 spans the full extent (∼50 pc) of the supernova remnant W50 (Mirabel & Rodriguez (1999) and Rodriguez et al. (1992)).

4   Conclusions

The hitherto poorly studied radio source 18P87 has been serendipitously shown to have the structure of an astrophysical jet. We suggest that it may be a Galactic object. While the distinction on the basis of physical properties is not totally conclusive, the Galactic interpretation relies on the absence of H I absorption of the continuum emission beyond the middle of the local gas. If it is indeed a Galactic structure its non-thermal radio emission classes it as a microquasar. We suggest that it is only sporadically active and that the structures we have observed are the remnants of interaction with a dense interstellar environment.

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